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**INTERIM
TASK FORCE REPORT ON
HIGH TEMPERATURE SUPERCONDUCTIVITY**

87-314-K

HTSC Task Force

job	file	date	report no.
15-542 16-722	811.4	January 7, 1988	87-314-K



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EXECUTIVE SUMMARY

The recent discovery of High Temperature Superconductivity (HTSC) at transition temperatures up to 90 K is an important scientific achievement. The sheer surprise of this discovery, as well as its potential scientific and commercial importance, largely underlie the degree of excitement and public interest of the field. Although the applications of conventional superconducting materials which require cooling at liquid helium temperature of 4 K have been investigated before, most studies concluded that even for the most promising power system components, such as underground cables and generators, large scale application was not economically feasible. The recent discovery of HTSC materials has the potential to change the techno-economic picture of application. With the intense public interest and media focus on HTSC applications in the power system, utilities have to respond to many questions regarding this emerging technology. At the same time, power system engineers have started to re-examine applications with the new information about the material. What are the promises and limitations of the material? What is the impact on Ontario Hydro? How can Ontario Hydro exploit the opportunities offered by HTSC?

In April, 1987, a HTSC Task Force was formed to monitor the technology development, to assess the impact, and to identify future opportunities. Of the 14 Task Force members, nine are from the Research Division, and five from other divisions in the Corporation. The objective of this Interim Task Force Report is to summarize what we know about the material and our perspective on future development. The Task Force concluded that the existence of high temperature superconducting material, mainly yttrium barium copper oxide, at transition temperatures of 90 K, has been confirmed by the scientific community. The existence of a room temperature superconductor (transition temperatures of 300 K) is uncertain. Although scientists are actively pursuing the isolation of room temperature superconducting materials, at present there is no firm evidence that this can be achieved.

While the base of experimental knowledge on the 90 K material is growing rapidly, there is as yet no generally accepted theoretical explanation of its behaviour. Much research is needed to optimize the 90 K material's properties so that it can be used under practical utility conditions. The material's low critical current density may be a major hurdle in the optimization process. The fabrication and processing challenges presented by the HTSC material suggest that the period of development for applications in the power system will probably be long-term and may extend for a decade or more.

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Despite the less than optimum material properties for power system application, the Task Force felt that material scientists and engineers may eventually be able to optimize and fabricate the material according to the set requirements. The Task Force also concluded that the application of HTSC materials in the power system may have an impact on the supply and demand of electrical energy.

Preliminary analysis of the possible advantages of HTSC machines over conventional equipment in key areas of the power system operation is presented in this report. The advantages include up to 1% increase in efficiency and improved stability of generators, low loss underground transmission cables, up to 0.2% increase in efficiency of transformers, daily load leveling and power system stabilization by superconducting magnetic energy storage devices. More efficient motors and rotating machines may have an impact on the demand for electrical energy. Although some advantages can be identified and assessed, the cost and effort required to develop HTSC machines can not be evaluated at the present time because there is not enough information about the material's properties and fabrication cost.

In order to be in a position to fully exploit HTSC technology and to respond to external expectations, Ontario Hydro should adopt a strategy. The Task Force recommends a strategy which calls for close monitoring of research trends, feasibility assessment and ranking of potential applications.

The Task Force further recommends that the Corporation undertake a 2-year work program with major tasks in information gathering, application studies, and material technology. The objective of the program is to ensure that the Corporation will be in a position to implement the most cost-effective options should the advances in HTSC material development in the next two years reach a point that large scale application in the future is a distinct possibility. The 2-year program is to be carried out by the Research Division with assistance from Design & Development (Transmission and Generation), System Planning, Power System Operation and Corporate Programming Divisions.

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research division**

To: Dr. D. Mills
Director of Research

**INTERIM TASK FORCE REPORT ON
HIGH TEMPERATURE SUPERCONDUCTIVITY**

HTSC Task Force

1. INTRODUCTION

Recent developments in high transition temperature superconductivity (HTSC) have generated enormous interest in the scientific communities and have attracted much media attention. Although the applications of conventional superconducting materials in the electric power system have been investigated before, most studies concluded that, even for the most promising power system components such as cables and generators, large scale application was not economically feasible. The rapid advances of scientific achievement in the past few months have the potential to change the techno-economic picture. The discovery of superconducting materials above liquid nitrogen temperature (77K) breaks an important technical and psychological barrier. Many scientists compared the discovery with the invention of the laser and the transistor. Not only is the discovery significant, to many scientists it is the speed of development which surprises them. With the intense public interest and media focus on applications such as lossless transmission lines, energy storage systems and magnetic levitation trains, utilities have to address many questions, and at the same time, system engineers must start to re-examine applications with the new information about the material. What are the savings and opportunities for the utilities? What are the potential impacts? What are the advantages and disadvantages of the HTSC material?

In order to address the questions of impact to the Corporation, a High Temperature Superconductivity Task Force was formed in April 1987. The Task Force members were from the Research Division and five other divisions in the Corporation (Table 1-1). The Task Force has the mandate to monitor the development, to assess the impact of the technology on Ontario Hydro and to identify future opportunities. With the technology advancing so rapidly, the Task Force found it difficult to follow the rapid progress, let alone evaluate the impact on the Corporation. Despite the lack of reliable information about the superconducting material, the Task Force members were able to carry out a preliminary evaluation. The objective of this interim Task Force report is to summarize what we know about the material, our perspective on future development, and to discuss issues facing the Corporation in view of the recent development. Finally, this report discusses an interim strategy which Ontario Hydro should adopt to exploit the opportunities offered by the technology. It should be emphasized that, at this stage, the technology is still advancing very rapidly; therefore, any formulation of strategy should be reviewed periodically.

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Table 1.1

ONTARIO HYDRO HTSC TASK FORCE

<u>Division</u>	<u>Member</u>	<u>Area of Interest</u>
Research	Dr. I. Balbaa	Ceramics, Fabrication
	Dr. G. Gowda	Material Chemistry Chemical Characterization
	Dr. T. Byrne	Mechanical Properties
	Dr. F.Y. Chu (Chairman)	Physics, Underground Transmission
	Dr. S.M. Harvey	Electrical & Magnetic Measurements, Cryogenics
	Mr. D.C. Lee	Power System Applications, Generators
	Dr. P. Mayer	Material Science, Characterization
	Mr. P.K. Mukherjee	Geotechnical
	Dr. C.J. Simpson	Material Science, Application
Design & Dev - Trans	Mr. D.J. Horrocks	Transmission Design
Design & Dev - Gen	Mr. B. Seckington	Alternate Energy Systems Energy Storage
System Planning	Dr. J.P. Bayne	Power System Applications, Energy Storage
Power System Operation	Dr. M. El-Kady	Energy Resource Utilization Power System Applications
Corporate Programming	Dr. M. Khanna	Strategic Planning

SECTION 2

SUMMARY OF DEVELOPMENTS

2.1 Conventional Superconductors

Superconductivity is a phenomenon by which material loses its electrical resistance below the critical transition temperature T_c . Superconductors exhibit the Meissner Effect in which the material expels any externally applied magnetic field. The phenomenon of superconductivity was discovered in 1911 when scientists found that mercury lost its electrical resistivity at 4K (-269C). In the past 70 years, the search for superconducting materials with high transition temperatures has become one of the key research areas in condensed matter and low temperature physics. Prior to the recent discovery of HTSC, the highest transition temperature materials discovered were the alloy niobium-germanium and niobium-tin alloy which were the design materials for conventional superconducting cables and generators. These conventional superconductors have transition temperatures ranging from 15K to 23K. The application of conventional superconductors requires expensive cryogenic equipment operating at the liquid helium temperature. The combination of high capital cost (mainly from refrigeration equipment), and high operating cost (from cooling), is the major hurdle for wide spread applications of superconducting materials. At present, these conventional superconductors are applied in specialized areas such as superconducting magnets for scientific investigations and magnetic resonance imaging machines for medical diagnostics.

2.2 High Temperature Superconductors

The first hint of major breakthroughs in high temperature superconductivity research appeared in a paper published by J.E. Bednorz and K.A. Muller of the IBM Zurich Research Laboratory. The new class of superconductor is a ceramic oxide material as compared to the pure metal and metal-alloy superconductors. Broadly speaking, the new HTSC materials can be divided into three classes according to their critical transition temperatures T_c . Table 2.1 shows the various compounds which exhibit superconducting properties at 40K, 90K and above 155K. It should be emphasized that at the time when the report was prepared, there was not sufficient evidence to confirm that room temperature (above 155 K) superconductivity exists.

Despite the wide variation in T_c , the new HTSC materials basically consist of copper oxide doped with barium and rare earth elements such as yttrium. With intense pursuit, scientists were finally able to determine the structure of these compounds with a high degree of confidence. Appendix 1 shows the molecular structures in more detail.

One key result from the determination is that all oxide superconductors are oxygen-deficient compounds in which the atoms are arranged in a structure classified as a perovskite. At present scientists suspect that oxygen and the vacant oxygen sites play an important role in determining the superconducting properties of the material. However, there is a lack of fundamental understanding of the conduction mechanism in the HTSC material, and this lack of knowledge impedes the optimization of material properties and the ability to increase T_c .

Table 2.1

High Temperature Oxide Superconductors

<u>Transition Temperatures</u>	<u>Materials</u>
40 K	$\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$ $\text{La}_{1.85}\text{Ba}_{0.15}\text{CuO}_4$
90 K	$\text{Y Ba}_2\text{Cu}_3\text{O}_{7-x}$ Any rare earth except Ce
150-300 K	$\text{Y Ba}_2\text{Cu}_3\text{F}_2\text{O}_y$
(?)	(yet to be confirmed)

The major advantage of HTSC over conventional superconductors is in the reduction of cooling energy to maintain the material below the critical temperature T_c . Liquid nitrogen at 77K, takes about 25-50 times less energy for cooling than liquid helium at 4K. Table 2.2 shows the benefits of raising the transition temperature from 4K to 77K. The 50 times reduction in cooling energy cost represents a considerable saving in the life cycle cost of large scale superconducting machines.

2.3 Fabrication

The fabrication technique for the 40K and 90K materials are very similar to conventional ceramics production methods by calcination of the powder mixture and sintering of the pressed form into the final product. There are many variations of this solid state reaction technique to make the HTSC material into bulk materials, thin film, wire and other forms. Table 2.3 outlines the fabrication techniques for bulk and thin film HTSC materials. Despite the simplicity in making bulk material, scientists have not yet been able to make the material with properties to satisfy requirements such as critical current densities, ductility, stabilities, etc.

Scientists have found that the yttrium barium copper oxide (YBCO) compound has many phases and only one phase exhibits the superconducting property. The ceramic oxide material consists of many grains packed together to form the bulk material. Due to the grain boundary phenomenon, poly-crystalline material exhibits properties quite different from that of the single crystal which is the ideal structure. For example, scientists have found that the critical current densities in a single crystal are much higher than polycrystalline material which contains many small single crystal grains (10-40 μm). Fabrication techniques to minimize grain boundary effects are required to increase the current carrying capability of the superconductor.

Table 2.2
Cooling Energy Comparison

Refrigerator Ratio

Amount of power required to remove
1 Watt of heat dissipation*

	<u>Theoretical</u>	<u>Practical</u>
Liquid N ₂ (77 K)	3	6-10
Liquid H ₂ (20 K)	14	50-100
Liquid He (4 K)	73	300-500

*Ambient temperature at 295 K

Table 2.3
Material Fabrication

Bulk	1)	Conventional ceramic process - calcination, sintering
	2)	Conventional with improved powder preparation - ultrafine, mono-size powder - sol-gel/organochemical process
	3)	Encapsulation - forming and swaging in tubes and wires with silver or other metal tubes
	4)	Melt spin process melting of metals, and oxidization in O ₂ atmosphere dropping of molten metal in spinning plate rapid cold quench becomes thin ribbon
Film	1)	Electron beam - 3EB (IBM)
	2)	Plasma spraying
	3)	Laser - deposit thin film on SrTiO ₃ substrate using pulsed excimer laser evaporation
	4)	Chemical vapour deposition

Table 2.4

Electrical and Magnetic Properties

Y-Ba-Cu-O System

Resistivity ρ (normal)	300 $\mu\Omega$ - cm
Resistivity ρ (sc)	$<3 \times 10^{-14} \Omega$ - cm
J_c (bulk)	10^3 A/cm^2
H_c	$>35 \text{ T}$
T_c	92 K
ΔT_c	1 K
Magnetic flux expulsion	100%

Table 2.5

Critical Current Density (A/cm^2)

Y-Ba-Cu-O

Bulk	10 - 1000	
Wires	1 - 500	
Thin Film*	10^5 10^6	at 77 K at 4 K
Theoretical Limit	10^7	
Conventional niobium based superconductor	10^6	at 4 K

* Values for single crystal film. J_c depends on the current direction and decreases with increased magnetic field.

2.4 Material Properties

Many electrical, magnetic and mechanical properties of the 90K material have been determined and some of the critical parameters are listed in Table 2.4 and 2.5. At normal temperature, the HTSC material has an electrical resistivity of $300 \mu\Omega - \text{cm}$ which is between a good semiconductor and a poor conductor. The major improvement required in the electrical properties before application in the power system can be considered is the critical current density. At 10^3 A/cm^2 for a polycrystalline bulk material, this value is 100 to 1000 times lower than that for a conventional superconductor and is considered to unacceptable for practical applications. Although critical current densities of 10^6 A/cm^2 have been achieved in single crystal film, the fabrication of such film for bulk application in the power system will require substantial research and development effort in the future. The critical magnet field of 35 Tesla is a satisfactory value for application in conductors and electromagnets.

The HTSC material has mechanical properties similar to ceramics. The fracture toughness value is low and is similar to that of ordinary glass. The material's brittle properties and lack of ductility require that it should be fabricated in a way to overcome these hurdles. The material can take up oxygen in an oxygen rich atmosphere or lose oxygen in a reducing atmosphere. Since the oxygen content is critical to the superconducting properties, the material's stability depends greatly on its environment. In addition, the material is affected by moisture and high humidity. Although no toxic information is available for the sintered material, the powders with which the material is fabricated are classified as toxic and must be handled with caution.

2.5 Conduction Mechanisms

Despite intense efforts by physicists, there is still no satisfactory explanation for the high transition temperature of the ceramic oxide superconductor. The conventional theory of electron pairing first proposed in 1956 can not explain all the observations such as high T_c and low critical current densities.

The mechanism for electron pairing is still a mystery. Experimental evidence has shown that the electron coupling via the crystal lattice vibration (phonon) is not the dominant mechanism, and other mechanisms such as exciton, plasmaon, etc, require further verifications.

The lack of adequate knowledge of the conduction mechanism is the major impediment to material optimization. Although many scientists believe that the copper-oxygen bond and the layering structure of the crystal lattice affect the conduction electron, there is no information on how such a structure may lead to pairing. The scientific community, as yet, has no clues to improve the structure and increase the pairing energy.

Another area where the scientist has little information is in the grain boundary. The conduction mechanisms across the grain boundaries are not known.

2.6 General Assessment

1. Existence of a superconducting material with transition temperature of 90 K has been confirmed. The increase in transition temperatures from 23K to the 90K is a major scientific achievement. There are many unconfirmed reports about observations of room temperature (above 150 K) superconductors. Preliminary reports indicate that the major hurdle appears to be in the isolation and stabilization of the room temperature superconductivity grain in the 90K oxide superconductors. However, the existence of room temperature superconductor has not yet been confirmed.
2. Critical properties of the 90K materials have been measured and substantial improvements in critical current densities, mechanical properties and stabilities are required before practical applications can be realized. The key to achieving the desired properties appears to be in material fabrication. Much research is needed to optimize the fabrication and shape-forming process so that wires and conductors can be manufactured. The advances in material sciences and ceramic technology in the next five years will be critical in determining the feasibility of application in the power system. Ontario Hydro should closely monitor these advances in order to exploit the potentials of HTSC in the future.
3. The lack of a suitable theory to explain the conduction mechanism is the major impediment to material optimization. Given the already complex crystalline structure, it is important for scientists to gain some basic knowledge so that fabrication process can be improved.
4. The discovery of HTSC material has caught the imagination of many scientists and engineers. The tremendous increase in efforts by the academic community and governments has stimulated much progress in material R&D. Barring any major unforeseen technical problems, it is possible that the hurdles discussed above for the 90 K material may be overcome systematically by future R&D effort. At present, universities and government laboratories, mainly in the US and Japan, are leading such efforts.

SECTION 3

IMPACT ON ONTARIO HYDRO

In assessing the impact of HTSC on Ontario Hydro, the following two questions must be addressed:

- 1) How will this new technology affect the generation, transmission and distribution methods which the electric utility industry uses now?
- 2) What impact will the application of HTSC materials, devices and systems have on the demand for electricity?

3.1 Supply of Electricity

The impact of superconducting materials on the supply side of the power system has been assessed in many studies in the sixties and the seventies when conventional superconductors were developed. Most studies concluded that although the application of superconducting materials in the power system did indeed lead to improved efficiencies, the capital cost and the cooling energy requirements were so large that it was economically not feasible to implement superconducting devices and components in the power system. The major impact of the recently discovered superconducting materials is that the cooling energy cost can be significantly lowered by as much as a factor of 50 if the system could be operated at liquid nitrogen temperature instead of liquid helium temperature.

Table 3.1 lists some of the possible major applications of HTSC on generation, transmission and power system operation. Details of the benefits and the difficulties in the applications are discussed in the following sections. Table 3.2 lists the material requirements for these applications. With the exception of critical current density, the new HTSC material appears to meet the critical magnetic field and transition temperature requirements.

3.2 Generation

By replacing the electromagnet windings in the rotor of the generator, the size and weight of the generator can be reduced by up to 50% and efficiencies can be improved by 0.5 to 1.0%. A 1% increase in efficiency of a 500 MW generator can translate into \$25 million over a 30 year period life of the generator. The reduction in size and weight may also lead to increased rotor mechanical stability, thus requiring less maintenance and providing improved availability once the initial problems have been solved. Studies have also shown that the application of conventional superconducting materials in both the rotor and the stator could yield improvement in efficiency up to 1.3%.

Superconducting rotating machines in the 20 MVA range using conventional niobium alloy superconductor and liquid helium refrigerant technology have been designed and built for demonstration purposes. Larger machines in the 200-300 MVA range are in the design stage. However, the lack of demand in power generation equipment in the past decade has significantly slowed the development of superconducting rotating machines. The new HTSC technology will significantly lower cooling requirements, reduce the need for extensive thermal insulation in the rotor and simplify the rotor construction. The detailed economic benefits for using HTSC materials in generators will need to be examined closely.

The longer term application of HTSC materials in generation are in fusion devices and magnetohydrodynamic generators. In both cases, the ability of HTSC material in generating extremely high magnetic field (up to 20-30 tesla) for magnetic confinement in fusion reactors and MHD generators may accelerate the development of these novel generation schemes. Again, the benefits of HTSC compared with conventional superconductors are mainly in the reduction of cooling energy cost in the superconducting magnet operation.

Table 3.1

Possible Applications in the Power System

- * Supply of Electrical Energy
 - SC generators and rotating machines
 - Low loss SC underground cables
 - SC energy storage for diurnal load leveling
 - SC energy storage for stability control
 - Fault current limiters and transformers
 - SC magnets for fusion and MHD devices
- * Utilization of Electrical Energy
 - Magnetic levitation train
 - Motors
 - SC in magnetic resonance imaging machines
 - SC in scientific instruments and apparatus
 - Novel new applications

3.3 Transmission

The reduction of transmission losses and the potential to carry high current are the major advantages of superconducting cable. Contrary to popular believe, there are some ac losses in superconducting cables although the dc loss is negligible. The total energy loss through the Ontario Hydro system (transmission and distribution) was about 8% in 1985. A complete elimination of the transmission loss (4%) could theoretically save about \$150 million per year in energy cost. However, preliminary analysis has shown that unless room temperature or much higher transition temperature superconductors are available, the HTSC materials in present form can not be used in overhead lines because the conductors still require protective jackets and cooling ducts. Therefore, superconducting cables can only be used for underground power transmission. The high cost for trenching and cable laying will more than offset the savings offered by a superconducting underground cable. In the foreseeable future, HTSC materials only have potential for use where underground power transmission is required for other reasons.

TABLE 3-2

REQUIREMENTS ON SUPERCONDUCTING WIRES FOR ELECTRICAL POWER APPARATUS

Power Apparatus	Electrical Characteristics			Mechanical Characteristics		Thermal Characteristic		Remarks
	Current Density A/cm ²	Magnetic Field (T)	Change in H (T/sec)	Tension ₂ (kg/cm ²)	Material Form	Thermal Loss	Stability Requirement	
Generator	15000 ~20000	~6.0	7.0 ~15	400	Wire Structure	10 ~40 kW/m ³	Medium	Machine Capacity 0.3 ~1 GW 20 kV - 30 kV
Transformer	4000	<0.5	<150	Under Review	Wire Structure	25 kW/m ³	Small	1 GVA 22/500 kV 60 Hz
Cable	13000 ~16000	0.1	(30)	Under Review	Cable Structure	0.2 W/m ²	Medium	1 ~3 GW 6.6 kV
Energy Storage	3000	8.0	-0	5000	Cable	Under Review	Large	5 GWh (1 GW x 5 hr) 3.6 kV 700 kA

TABLE 3-3

BENEFITS OF SUPERCONDUCTING POWER APPARATUS

Power Apparatus	Specific Benefits	General Benefits	Benefits of using oxide HTSC
Rotor Generator	0.5 ~1.0% Improve efficiency (50%) Reduced Size (50%) Reduced Weight	Stability improvement Low speed increase 1.3x High speed increase 1.7x	Simplify Rotor construction Cooling efficiency
Rotor & Stator	(0.8 ~1.3%) Improve Efficiency	Stability Improvement	Efficiency improved (compared to conventional SC)
Transformer	(0.1 ~0.2%) Improve Efficiency (60%) ~Weight (40%) ~Size	Connection to other HTSC components in power system Fault current limiting	Simplify construction and insulation Improvement in Cooling efficiency
AC Cable	Improved Efficiency 1/10 loss of Oil Fill Cable Small size 500 kV 5 GVA 1/4 size of Oil Fill Cable	Long distance transmission Increase current capacity Low voltage	Simplify cooling and thermal insulation, material size, etc Reduction in capital cost Cooling energy savings
Energy Storage	Increase in capacity	Storage efficiency >90%	Thermal insulation simplified low investment cost Cooling efficiency improved

Previous analyses have shown that conventional superconducting cable can only compete with underground cables such as oil filled or SF₆ cables if its ampacity exceeds 5000 MVA. At that capacity level, the loss of the superconducting cable is about 10% of the loss in oil filled cable and the size is about 25% (Table 3.3). Due to the lack of cost information on material and cable fabrication, it is impossible at this stage to compare the cost between conventional superconducting cable and HTSC cable. Therefore, the question of whether HTSC cable may be able to compete with oil-filled or SF₆ cable at a lower MVA rating in the range of 500 to 3000 MVA cannot be answered. However, one thing is clear, the critical current density of the material will affect the final cost of the cable. A preliminary analysis have shown that the cost of a HTSC cable could vary from \$800 to \$13000/MVA/km for critical current densities of 10^5 and 10^3 A/cm² respectively. At \$800/MVA/km, the HTSC cable could compete with conventional underground cables. figure can certainly compete with conventional underground cables.

3.4 Power Apparatus

The application of conventional superconducting materials in power apparatus such as transformers, fault current limiters, reactors and stabilizers has been studied. The ability of the superconducting coil to carry high current and generate high magnetic field lead to improvements in operating characteristics of power apparatus and the power system. In the case of SC transformers, the requirement for critical current density and mechanical stability are less stringent than that in generators. However, the marginal improvement in efficiency (0.1 to 0.2%) makes most superconducting transformer designs uneconomical. The biggest pay back in SC transformers may be in the reduction in size and weight by up to 50%. The finite a.c. loss in SC transformer is the major obstacle to higher performance. In a previous Westinghouse study based on conventional Niobium tin alloy, it was concluded that at ratings higher than 400 MVA, the life-cycle cost of superconducting transformers may be competitive with conventional transformers. The introduction of HTSC may further reduce the weight and size and operating cost of this component, thus making it competitive at lower MVA ratings.

The transition of a superconducting state to normal resistive state can certainly limit the current during a fault. A fault current limiter based on the principle of superconducting to normal transition can be designed. Another method for limiting the current in the grids employs the super-transductor principle. The transductor is a device for rapidly introducing inductance into a power circuit whenever the current rises above some predetermined limits. It does this by having an inductor with an iron core in series with the line, but with a dc winding around the core which drives it into saturation and so reduces the reactance of the inductor. If the ac current rises above a certain limit, the core of the inductor is driven out of saturation and a large voltage drop occurs across the inductor which limits the ac current rise in the system. Small fault current limiter using the above principle have been built at 5 MW and 3 kV level for feasibility studies.

3.5 Superconducting Magnetic Energy Storage (SMES)

Another application receiving considerable attention from utilities is the use of superconducting coils to store electricity. Such a coil would be charged during off peak hours by using power from baseload generators, then discharged during peaks, thus reducing the need for expensive cycling power plants. A study carried out by Bechtel International Inc showed that the capital cost for a 5000 MWh SMES operating at liquid helium temperatures may cost about \$1.3 billion, but the cost for load leveling is competitive with other storage schemes such as pumped storage. Preliminary analysis of Ontario Hydro's power system operation indicates that based on a 5000 MWh SMES plant, the seasonal storage energy saving is in the order of \$12.7 M/year. The daily

storage saving is about \$4.7 M/year. Additional benefits includes up to 1000 MW of equivalent maneuvering capability. Such capability is especially attractive in view of the large nuclear baseload at Ontario Hydro. The possible reduction of the number of scrubber installations and deferral of generation are other attractions. Further studies are required to show the costs and benefits of SMES application in the Ontario Hydro system.

The applications of HTSC materials in SMES may lead to a reduction of 5 to 15% capital and maintenance cost as compared to conventional superconducting SMES. The large variance is due to the uncertainty in the HTSC properties and the fabrication cost.

Despite SMES's many attractive features, any such system would pose unique engineering challenge. One important consideration is size. A 1000 MW design would require about 1 km in diameter of underground storage space. The outer boundary for such a facility would have to be more than 5 km in diameter because of the high magnetic field generated. Due to the immense magnetic force, the SMES coil must be stored underground against solid bedrock for stability. The high magnetic field would also pose many environmental problems.

A much smaller scale SMES may be used in the power system as a reactor or system stabilizer for short term energy storage purposes. These devices would have an energy storage capacity in the range of 30 MJ to 1000 MJ (0.3 MWh) as compared to the load leveling scheme of 18 TJ (5000 MWh). When used for dynamic or transient stabilization in the power system, these devices can temporarily store large blocks of power (10-500 MW) in the order of seconds for smoothing out any disturbance of transients in the system. A 30 MJ transmission line stabilizer, using conventional SC has been built and tested by BPA to stabilize the Pacific intertie when the dc line is out of service. A HTSC SMES may improve the operation characteristics and lower the capital cost and permit better utilization of the transmission system. The US military is actively pursuing the application of SMES for energy storage for the laser and particle beam weapons. Design studies have been initiated by the US.

3.6 Demand Side Impact

The impact on the demand side is more difficult to assess. Magnetic levitation trains, magnetic separators, magnetic resonance imaging machines all benefit from the discovery of HTSC materials. In general the efficiencies of any machine or device which uses electromagnets can be improved by employing superconducting windings. Although in theory a small SMES can be used to store energy for the electric vehicle, in practice the size of the superconducting coil is so big that it is not efficient to replace existing engines with SMES as proposed by many popular magazines. The introduction of superconducting magnetic levitation train may become a reality with the discovery of HTSC; however, major cost problems such as track installation still need to be solved. It has been pointed out that the superconducting magnet only accounts for less than 10% of the capital cost of the train system. The impact on the demand for electricity as a result of the introduction of magnetic levitation trains and magnetic imaging machines will be gradual and will likely be modest.

The impact of HTSC in motor design and hence its effect on the efficiency of motors is much more difficult to assess. While HTSC motors (assuming that a room temperature superconductor is available) would decrease the demand of electrical energy by reducing losses, the improved efficiency may lead to wider use of electrical devices and components by the industrial, commercial and residential sectors. One such example is the improvement in microwave cavities by HTSC coatings on the wall (to reduce skin effect loss) The improved microwave generation efficiency

may lead to wider use of microwave power for heating, drying and communications and therefore more electrical load.

Many scientists agree that one of the early applications of HTSC will be in electronics and computers. Although these two areas may not have a direct impact on the demand or supply of electrical energy, they may have an indirect impact. Superconducting switches using the principles of chips Josephson junctions, can process information about 10 times faster than circuits in conventional silicon. Adoption of Josephson junction technology to make faster computers could, therefore, affect utility operation because the electric power industry is the third largest user of computers. At Ontario Hydro, supercomputers may help system operators to acquire system parameters, optimize and control the power system on a real time basis to achieve maximum system operating efficiency.

3.7 General Assessment of Impact on Ontario Hydro

The impact of HTSC devices, components and systems on the supply of electrical energy has been discussed. The potential benefits are summarized in Table 3.3. Some of the major hurdles that need to be overcome are summarized in Table 3.4. While the benefits to various aspects of the power system operations may be quantified, the cost for implementation is not clear. This is partly due to the lack of adequate technical information about the material properties and the cost of fabrication. Without the knowledge of material properties it is impossible to assess the cost benefit ratio of applying HTSC in the power system.

Based on the available information, the task force did attempt to rank the various applications according to these benefits to the corporation and the technical complexities of each applications. Table 3.5 shows the results of such ranking. It is interesting to note that while load leveling may yield the highest payoff to the corporation, it is the most difficult task to achieve and may require major investment and effort. The column labeled "sum" can be viewed as the trade off between benefits and engineering complexities.

Table 3.4

Major Material & Engineering Problems to be Solved

- * Improve critical current densities to greater than 10^5 A/cm^2
- * Investigate ac losses
- * Improve mechanical properties such as fracture toughness
- * Improve material stabilities
- * Investigate aging and compatibility problem
- * More efficient and cost effective fabrication techniques
- * Investigate environmental issues, eg magnetic field effects
- * Problem of electrical joints and contacts

While the applications discussed above may have an impact to the corporation in the future, the immediate impact is from the immense public interest. As a result of the press coverage of the subject, the public's interest in Ontario Hydro's reaction to the development of HTSC and the application of HTSC in the power system also increases. For example, the popular press vision of a complete superconducting transmission system has lead to many inquiries about replacing overhead transmission lines by underground cables. The excitement generated in the scientific community also lead to many inquires by universities, research organizations and government agencies on Hydro's perspective and future plans on the application of HTSC in the power system. Questions from public utility commissions about HTSC applications in the power system, and the effect on utility planing on generation , location of transmission lines and electrical rates have been raised on many occasions in a number of US and Canadian PUC hearings. A list of organizations and groups which have contacted Ontario Hydro regarding HTSC developments and applications is shown in Appendix 2.

3.8 Conclusions

- 1) Assuming that the 90 K material can be optimized in the future for practical applications, the long-term impact of HTSC on the supply and demand of electrical energy may be quite substantial, but the pay off will not come quickly (Table 3.6 summarizes the outlook).
- 2) While most potential benefits on the supply side can be estimated, the costs to exploit the opportunities are not clear. The lack of adequate knowledge on the HTSC material properties and fabrication costs prevent accurate evaluation of the cost benefit ratio.
- 3) The short term impact on Ontario Hydro is the immense public interest on the subject as a result of press coverage.
- 4) Because of the potential payoff and the need to respond to external interest, Ontario Hydro should adopt a strategy to identify the promises and limitations of superconductivity and exploit the applications which are most beneficial to the Corporation.

Table 3.6

Outlook*

Time Frame for Prototype Applications

* Diurnal energy storage	10-15 years
* Fault current limiters and power apparatus	10-15 years
* Generators	10-15 years
* Transmission lines	No agreement

- * This outlook is based on a Delphi forecast carried out by Dr. W.G. Hanson and Dr. R. Ramani. Eleven persons were surveyed in the study.

Table 3.5

Ranking of Benefits and Technical Complexities

	<u>Technical Complexities*</u>	<u>Benefit**</u>	<u>Sum</u>
* Energy Storage	1	2-3	3-4
* Generators	2	1	3
* Cable	3	1-2	4-5
* Power Apparatus - Transformer	3	1	4
- Fault Current Limiter	2	2-3	4-5
- Reactor	2	2-3	4-5
Magnetic Levitation Train	2	1	3
Magnetic Shielding	3	1	4
Fusion	1	1	2
Magnetic Resonance Imaging	3	1	4
Large Motors	2	1	3

- * Technical complexities (Ranking of 3 means lowest technical complexities).
** Benefits (Ranking of 3 means highest benefit).

SECTION 4

STRATEGY AND WORK PROGRAM

4.1 Ontario Hydro Strategy

The need for an Ontario Hydro strategy to deal with the emerging HTSC technology stems from internal and external factors. When the HTSC material becomes available for practical application, Ontario Hydro should be in a position to exploit the full benefits of this new technology to improve its productivity and maintain a competitive edge. At the same time, Hydro must respond to external expectations related to the development of this technology as it evolves into a high technology race among industrialized nations. Appendix 3 lists some major activities planned by various nations, including Canada.

As a producer of electrical energy and a major user of electrical equipment, Hydro's pursuit of the promises offered by HTSC would obviously be different from that of the major equipment manufacturers such as Westinghouse or IBM. It is not in Ontario Hydro's interest to focus its resources and effort in material and wire development. However, Ontario Hydro should be in a position to identify, select and specify areas of applications and hardware which will be most beneficial to the Corporation. In other words, Ontario Hydro has to be an informed buyer and user of the technology. To achieve that goal Ontario Hydro should be technically prepared for the complex issues facing the development and application of this technology.

As the technology is advancing rapidly, any strategy adopted by Hydro should respond to changes from external developments. The strategy advocated by the HTSC Task Force is short term in nature and Hydro should be prepared to alter the strategy in the future under changing circumstances. The strategy calls for Ontario Hydro to monitor the full research and development picture, assess the feasibility of, and prioritize the application of HTSC, act as a catalyst in technology development, and make sure that applications are responsive to the Corporation's needs.

Associated with the strategy is a two-year work program to be carried out by the Research Division, with assistance from Design and Development Division, System Planning Division, Power System Operations Division and Corporate Programming Division. The three major elements of the HTSC program are:

- 1) Information Gathering
- 2) Application Studies
- 3) Material Technology

At the end of the two year program, Hydro should be in an excellent position to identify the promises and limitations of the technology so that the Corporation can decide whether to take further steps for development, demonstration and implementation of the technology. The estimated cost of the program is \$420K in 1988 and 1989. The major expenses will be in labour cost. It is expected that most of the effort will be spent by the Research Division in sub-program 1 & 3, while the the other divisions will actively participate in sub-program 2.

Table 4.1 shows approximately the level of effort (mainly manpower), which should be devoted by the Research Division and other divisions on each sub-program in the two years. Detailed description of the programs are presented in the following sections. Appendix 4 lists some specific tasks that each division or department will be interested in devoting efforts in the 2-year program.

Table 4.1

Level of Effort by Research Division and Other Divisions (\$000)

	<u>Information Gathering</u>	<u>Application Studies</u>	<u>Material Technology</u>	<u>Total</u>
1988	\$40 R*	\$120 R 80 N**	\$180 R	\$340 R 80 N
1989	\$60 R	\$150 R 150 N	\$220 R	\$430 R 150 N
Total:	\$100	\$500	\$400	\$1000

* Research Division
** Other Divisions

4.2 Information Gathering & Monitoring

The Need

Since the announcement of the discovery of HTSC, there is an information explosion about the subject. The number of researchers increased exponentially. In order to be technically informed about the development, it is important to set up an information exchange network with other utilities and research organizations. At the same time, information collected can be channeled to interested parties within Ontario Hydro. Clearly there is a need to establish an efficient information network to collect and disseminate information about the HTSC material properties, research trends, application developments and activities and responses outside Ontario Hydro.

Objectives

- 1) To collect the necessary information related to the development of HTSC materials, devices and systems.
- 2) To inform Hydro personnel about the development and to develop a data base on HTSC material properties and characteristics.
- 3) To liaise with external groups and organizations concerning Hydro's interest and perspective on HTSC.

Approach

Since the HTSC technology is still in the research phase, much information is from universities and research organizations. Therefore, a strong tie with university groups in the initial stage

would help to achieve the goal. In order to obtain the necessary technical information, Ontario Hydro must be active in the research field so that information can be exchanged. Therefore, this program is closely related to program 3 in material research. Since the formation of the Task Force, members in the Research Division have maintained close ties with universities (McMaster, Queen's, Brock, Carleton).

The pursuit of HTSC technology is a global effort. Interaction with research organizations and utilities outside Canada can also help us to gain information not available within Canada. Therefore this program also includes task for liaison with organizations such as the U.S. EPRI, EdF (France), CRIEPI (Japan), CERL (Britian), CEPEL (Brazil). The task force members have already established contacts with members of these organizations (with the exception of CERL).

To keep Hydro staff informed, a HTSC newsletter has been published by the Task Force. This newsletter updates the technical development and external and internal activities on a bimonthly basis. It is expected that the newsletter effort will continue in the future.

At present we have about 130 copies of the newsletter circulated internally. Since its publication, the newsletter has also been circulated to some external groups such as the National Research Council and the Canadian government labs. Recently the demand for external circulation has been growing and we have about 130 copies mailed to readers outside Hydro. The external effort is partially supported by the National Research Council.

Program Structure

Research Division is presently coordinating the information gathering effort. The Task Force chairman also serves as technical editor of the newsletter with assistance from the library. The Research Division should continue to co-ordinate the information gathering network and at the same time initiate the development of a data base on material properties and characteristics.

In addition to labor expenses, the Material & Expense (M&E) cost is in library search, electronic mail and data base development and some travel costs (attendance of important conferences).

1988	\$40,000
1989	\$60,000

4.3 Application Studies

The Need

Before the discovery of HTSC, most application studies concluded that the benefits of superconductivity for utilities were marginal. These studies are based on liquid helium cooled superconducting materials. The discovery of HTSC may change the techno-economic picture. For applications in the power system, engineers must re-evaluate the cost benefit ratio based on liquid nitrogen technology or even higher temperature refrigeration system. The material properties are different, so is the cost for fabrication. Utilities must have adequate information to decide whether it is worthwhile to spend the effort to implement the technology. Therefore it is essential that Ontario Hydro carry out a thorough application study program to assess the economic benefits.

Objectives

- 1) To evaluate the benefits that can be realized and the efforts required for major application of HTSC systems in the power system
- 2) To select and identify the technology areas in which Hydro might invest effort in the future.
- 3) To assess the demand side impact based on future HTSC material development.
- 4) To ensure that equipment manufacturer's development on superconducting machines are responsive to the Corporation's need

Approach

Present technology trend indicates that the 90K material (yttrium barium copper oxide) will most likely be used in large scale superconducting machine development. Such machines will be cooled by liquid nitrogen refrigerant and the cooling energy cost is based on the cooling temperature of 77K. While it is still not clear whether any room temperature superconducting materials can be developed in the foreseeable future, any model to evaluate the economic benefits should accommodate that possibility. Therefore a flexible model to take into account transition temperatures ranging from liquid nitrogen temperature (77K) to room temperature (300K) should be developed.

One of the major efforts of the application study program will be in identifying hurdles and limitations in the implementation of the HTSC technology. At the same time, the studies should also identify peripheral technologies which will be required in the future. Table 4.2 lists the possible peripheral technologies required for implementation. The application studies should address those issues as well.

It is obvious that Ontario Hydro cannot undertake all the application studies at the same time, but rather to select the most promising ones. The areas listed in Table 3.5 should serve as a reference. A small scale SMES for power system application may be the niche which the application study program may want to tackle first. This will provide the necessary background to investigate large-scale SMES devices for energy storage if the Demand/Supply Option Study indicates that such a study is warranted.

Since one of the challenges in the end-user area is to look for new opportunities that HTSC can provide, part of the application studies should be devoted to the exploration of novel ideas and new concepts which planners and engineers have never imagined before. Concepts such as a completely new power system based on HTSC components, new use of electricity based on new motors or computer technology should also be explored.

Program Structure

One of the difficulties in carrying out the application studies is the lack of technical and cost information regarding the material. Hopefully, program 1 & 3 should supply the necessary information as it is available. In order to achieve the goal of accurate assessment, the program should be tightly coordinated among the various divisions possessing the expertise. Therefore, active participation of the interested parties is essential.

It is expected that activities in the initial stage of the program will be limited to a few areas because information is not available. As more information becomes available, the level of effort will increase. The labor expense will be shared by the participating divisions including Research.

1988	\$ 200,000
1989	\$ 300,000

Table 4.2

Peripheral Technologies

(In addition to Material & Conductor Technologies)

- * Cryogenics Technology:
 - cooling system
 - control and instrumentation
- * Thermal Insulation Technology
- * Low Temperature Electrical Insulation
- * Magnetic Field:
 - environmental
 - measurement
- * Geotechnical:
 - UG cable
 - UG storage ring
- * Mechanical:
 - structural support (short circuit)
- * Diagnostics and Instrumentation

Table 4.3

Steps to Application

- | | | |
|----|-------------------|---|
| 1. | Processing: | Preparation of materials with desired properties T _c , H _c , J _c , mechanical, etc. |
| 2. | Fabrication: | Shaping of news material into wires/filaments, coils, tapes, cables, etc. |
| 3. | Characterization: | Necessary knowledge to relate properties to composition, microstructure, defects, stability and aging. |
| 4. | Demonstration: | Simple samples or devices (cables, motors) laboratory or industrial scale. |
| 5. | Manufacturing: | Techniques and equipment needed to achieve production to scale (size and quantity) and quality needed for applications. |

4.4 Material Technology Program

The Need

The transformation of HTSC materials to devices, components and systems for utility application is basically a material problem. Material scientists and engineers have to fabricate, process and make the materials according to specifications (see Table 4.3) for use in the electric power system. Table 4.4 shows a flow chart of R & D effort required to achieve such transformation for the benefit of the utilities.

It is not in Ontario Hydro's interest to pursue all the tasks outlined in Table 4.4 and Ontario Hydro has neither the resources nor the expertise to complete them. Universities, government research laboratories and industries, in Canada and elsewhere, hopefully will undertake most of the steps. The tasks of interest to Ontario Hydro are described in the shaded blocks of the flow chart. As a user of the HTSC technology, Ontario Hydro's main interest in material technology will be to acquire the necessary expertise so that the material can be evaluated and hopefully applied in a beneficial way to the power system.

On the supply side, there will be a need for material expertise in the design, specification, evaluation, operation and maintenance of power system components made from HTSC materials.

On the demand side, Hydro experts will be asked to evaluate performance of HTSC electrical systems, and to provide standards and facilities to test such systems for the public.

In order to satisfy the needs listed above, it is necessary for Ontario Hydro to acquire some basic knowledge in HTSC materials with the focus and emphasis on material characterization and performance evaluation. A HTSC material technology program within the overall corporate HTSC program is the best way to acquire the knowledge and expertise.

Objectives

- 1) To ensure that the development of the material will meet the requirements for applications in the power system.
- 2) To acquire the necessary expertise in the material technology area so that Hydro can quickly identify, specify and evaluate materials and devices which will be of potential benefit to the corporation. This is mainly in support of the Application Study Program.
- 3) To establish the abilities and facilities to characterize and evaluate HTSC materials and systems.
- 4) To acquire the material expertise to operate, maintain and examine HTSC systems in the future.

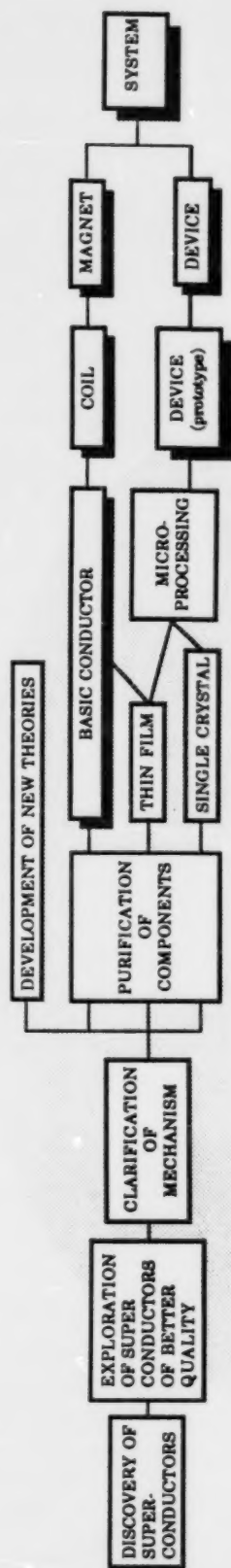
Approach

The major focus of the material technology program is in acquiring the necessary knowledge and expertise. This could be achieved through internal and external means. At the Research Division, expertise and facilities are already available in many areas relating to the characterization, property measurement and performance evaluation of metal conductors used in generators, transmission lines and other power apparatus. The fact that the new HTSC is a ceramic oxide operating at low temperatures requires additional research effort.

- 1) Characterization - Techniques are required to determine the microstructure and chemical composition of the ceramic oxide material under typical operating conditions. Material characterization is important in the determination of material integrity, stability, aging and failure mechanisms.
- 2) Property Measurements - Electrical and magnetic properties of any HTSC materials have to be determined for specific applications. Facilities and equipment to determine critical transition temperature, critical magnetic field, critical current densities, ac performance, high frequency characteristics and transient properties are required. Furthermore these properties should be measured as a function of temperature ranging from cryogenic to room temperature.

Techniques to measure mechanical properties such as strength and workability should be established.

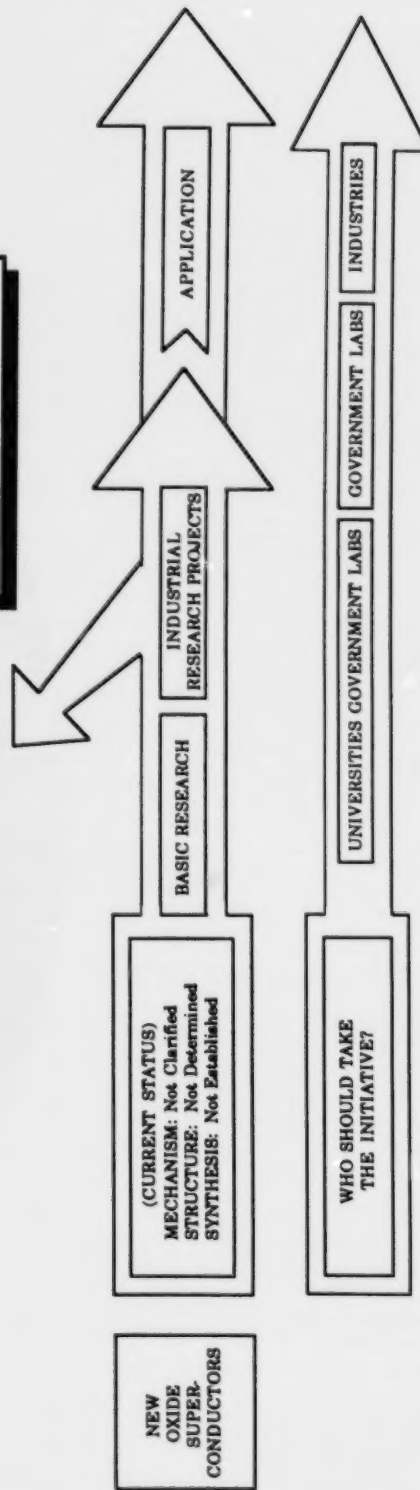
<< SUBSTANCE >> << MATERIAL >> << APPLICATION >>



CHARACTERIZATION (measurement of superconducting and relating properties
analysis of crystal structures, analysis of compositions, etc.)

CONSTRUCTION OF DATA BASE, FEASIBILITY STUDY OF APPLICATIONS OF SUPERCONDUCTORS

TECHNOLOGY TRANSFER



- Tasks of interest
to Ontario Hydro

FIGURE 4.4
FLOW CHART OF THE R&D OF SUPERCONDUCTORS

- 3) **Material Fabrication** - Although material fabrication is not the emphasis of the program, samples will be needed for the characterization studies. The samples can be acquired through external sources. However, in the initial stages of the program, a limited effort should be spent in the fabrication and processing area so that the researchers can become familiar with the techniques. In-house fabrication and processing effort should be compatible with the overall program effort and resources.
- 4) **Support of External Programs** - In certain technical areas, it may be more efficient to co-operate with other organizations such as universities or research institutions to achieve the objectives. The support of external programs and the participation in a consortium such as the Canadian University Industry Council on Advanced Ceramics (CUICAC), should be considered if such support enhances the in-house research and benefit the overall program.

Program Structure

The various tasks discussed in the previous section will be carried out by the Electrical Research, Metallurgical Research, Chemical Research and Mechanical Research departments of the Research Division. The emphasis of the program is on sharing of resources among these departments, thus avoiding duplications.

Highlights of the two year program are:

- 1) Establishment of a cryogenic electrical and magnetic property measurement facility (CEMMF) for HTSC materials. The facility should be able to measure all critical parameters of bulk superconductors and small size wires and cables from 30 K to room temperature. The facility should also be available for use by Ontario Hydro clients.
- 2) Establishment of a material characterization facility to analyze bulk, film and wire form HTSC. This includes work on investigation of grain boundary effects and microstructure analysis.
- 3) Formation of a HTSC material data base which includes data and knowledge relating to the fabrication, processing and properties of various types of HTSC.

The required budget for the material program

1988	\$180,000
1989	\$220,000

SECTION 5

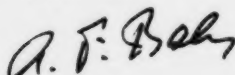
CONCLUSIONS & RECOMMENDATIONS

- 1) The existence of superconducting materials with transition temperatures in the 90 K range has been confirmed and the material properties have been measured. The pursuit of a room temperature superconductor by the scientific community is underway but there is no firm evidence that this can be achieved
- 2) Much research is needed to optimize the 90K material's properties, fabrication techniques and shape forming processes before wires, cables and components can be manufactured for use in the power system. The material's low critical current density is a major hurdle for future development.
- 3) The application of HTSC materials in the power system can have a significant impact on the supply and demand of electrical energy. HTSC machines have advantages over conventional equipment in key areas in the power system operation such as generation, transmission and energy storage. A preliminary analysis of the possible advantages is presented in this report. However, the cost and effort required to exploit these advantages cannot be evaluated at the present time because there is not enough information about the material's operating characteristics under typical utility conditions and its fabrication and operating costs.
- 4) In order to be in a position to fully exploit HTSC technology should the promises becomes a reality, and to respond to external interests, Ontario Hydro should adopt a strategy. The strategy calls for close monitoring of the research and development trends, assessment of the feasibility and prioritization of HTSC applications, act as a catalyst in technology development and make sure that applications are responsive to the Corporation's needs.
- 5) A 2-year program to be carried out by various interested parties from Research, Design and Development, System Planning, Power System Operation and Corporate Programming is recommended. The program will focus on information gathering, application studies and material technology. The objective is to ensure that the Corporation is in a position to implement the most cost effective options for the design and operation of the power system.

Acknowledgement

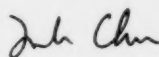
The HTSC Task Force would like to acknowledge the inputs from Drs. G.L. Ford, W.G. Hanson, R. Ramani, Messrs. M. Vainberg, P. Dick, R. Jeffreys, R. Quick, G.F. Pessione and R. Neuman.

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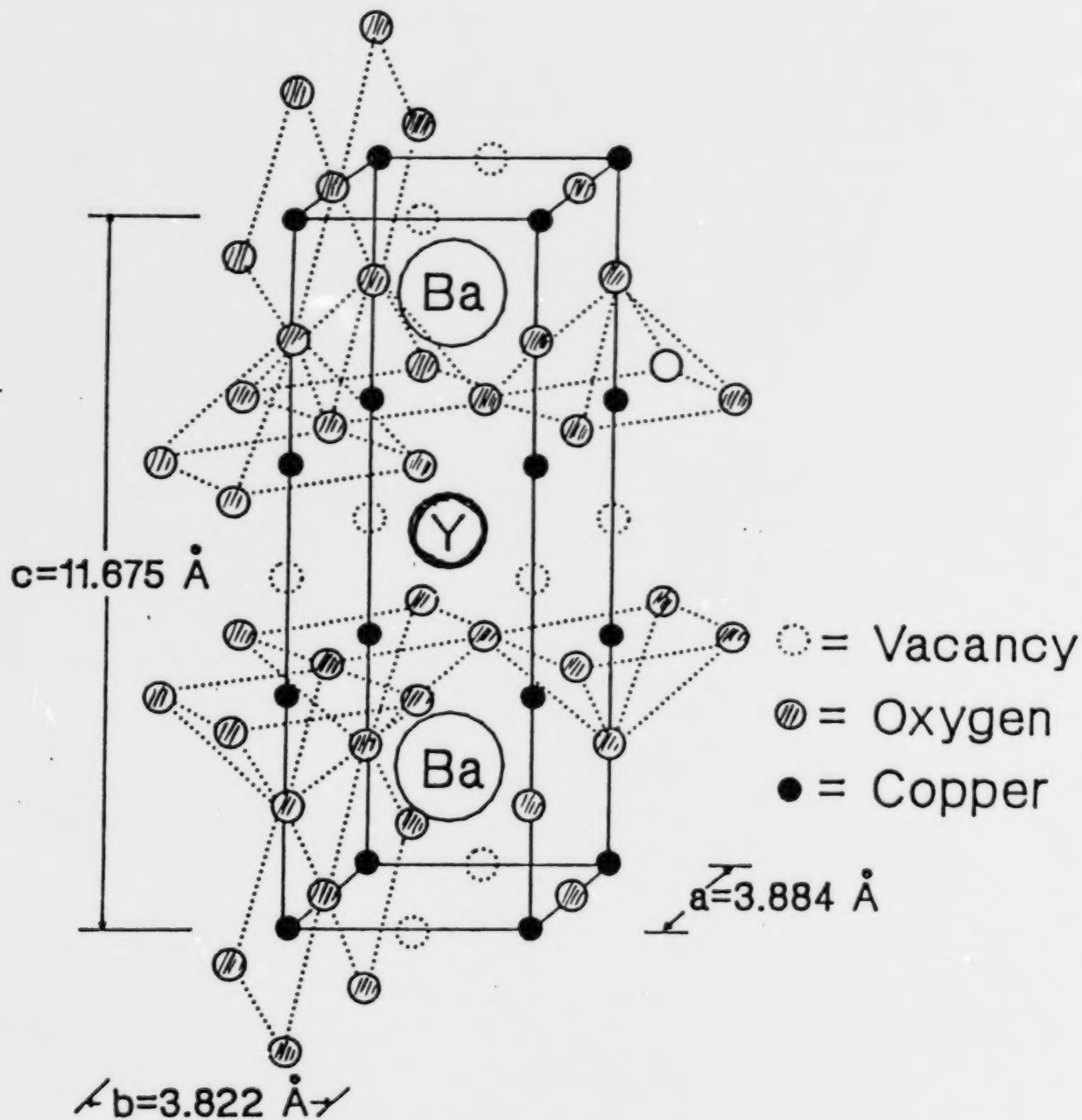
Submitted:



F.Y. Chu
Acting Section Head - Science
Electrical Research Department

APPENDIX 1

Structure of YBa CuO Superconducting Compound



APPENDIX 2

EXTERNAL INTERESTS

- **Inquiries from**
 - Public
 - Media
 - Other Ontario Hydro Groups
 - Invitations for Talks & Presentations
 - Public Hearings
- **Domestic Contacts**
 - NRC, NSERC, Ontario Ministry of Energy
IREQ, CEA & Other Utilities
 - Over 20 Canadian Companies, ALCAN
Bell Northern, CW&C, Electrofuel
- **International Contacts**
 - US EPRI , EdF, CRIEPI (Japan),
KEMA (Netherland), CEPEL (Brazil), China's EPRI
 - Canadian Department of External Affairs & Embassies

APPENDIX 3

WORLD WIDE ACTIVITIES

- USA
 - \$100 M national R&D effort in 1988
 - EPRI major SC program, UG transmission cable a priority
 - Universities, National Labs, Industries cooperation
 - Reagan's 11-point SC Initiatives
 - SDI Energy Storage Program \$60 M in 1988
- JAPAN
 - \$60 M R&D effort in 1988
 - Major role of CRIEPI in national program
 - Consortium of 13 companies to develop three 70 MW SC generators
 - Major efforts by Sumitomo, Hitachi, Toshiba and Mitsubishi
- CHINA, INDIA, BRAZIL, UK, GERMANY
 - Significant national R&D efforts
 - Previous experience in SC developments
- CANADA
 - University effort
 - Material Program at NRC
 - Consortia effort
 - Individual group interest

APPENDIX 4**AREAS OF INTEREST BY DEPARTMENTS AND SECTIONS**

		Information Monitoring	Application Study	Material Technology
Electrical Research	Science Stn & Ug Sys Studies Utilization	Newslet, Liaison	UG Cable, Gen SMES, Gen	Cryo,E&MM Fabrication
Metallurgy Research	Adv Mat Technology			Mat Charact Microscopy
Chemical Research	Mat Chem Analytical			Fabrication Mat Charact
Mechanical Research				Mechanical Properties
Divisional Projects		Liaison		
System Planning			Trans,SMES,PAS	
Design & Dev - Trans			UG Trans	
Design & Dev - Gen			Gen, SMES	
PSOD			Resource Util	
Corp Prog			Demand Side Impact	